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G. Bunce
16 October 2000
Spin2000, Osaka

The Muon $g-2$ Experiment at Brookhaven

1. What is $g-2$ and why measure it?
2. How do we measure $g-2$?
3. $g-2$ from the 1998 run at Brookhaven
4. The 1999 data and analysis

We had hoped to present a new number here, but we are not ready yet. We have decided to show you the new data and much of the analysis, demonstrating the data quality, and our understanding of it.

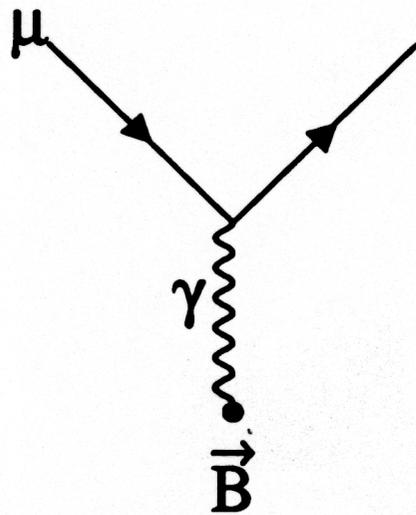
---1999 field (and the 2000 field map)

---analysis of the muon $g-2$ frequency for 1999

Note: We analyze the field and the $g-2$ frequency separately, with artificial offsets in each, known only to each independent group. When we are satisfied that the data are self-consistent and properly understood, with written reports on each and evaluated by the collaboration, and with the systematic errors for each determined, then we "open the box". We have no idea whether our present field and $g-2$ frequency are close or far away from theory.

g – Factor

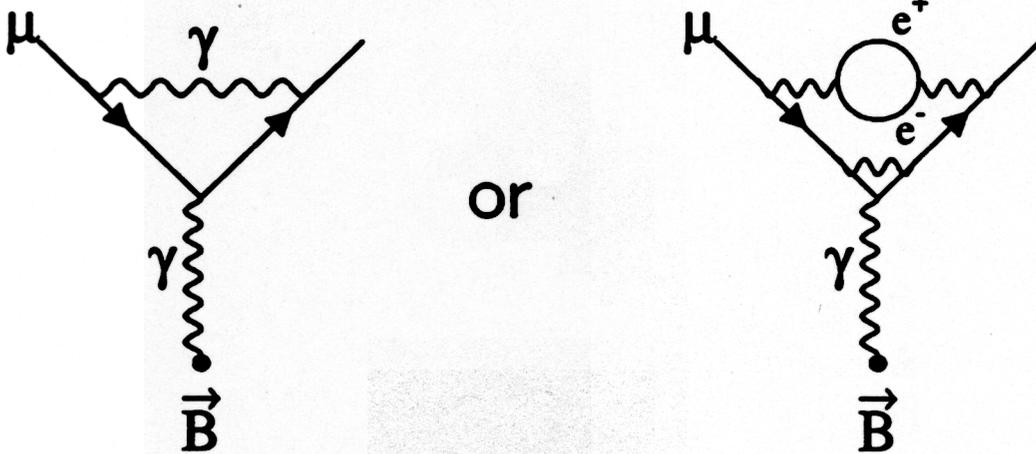
$$g = \frac{\text{magnetic moment} \left[\frac{e\hbar}{mc} \right]}{\text{angular momentum} [\hbar]}$$



$$g = 2$$

but . . .

... higher orders



lead to anomalous magnetic moment:

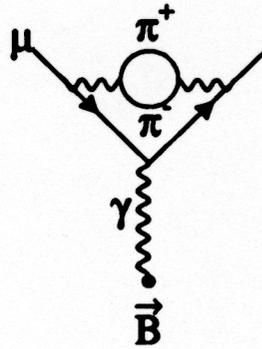
$$a = \frac{g-2}{2}$$

$$(a \approx 10^{-3})$$

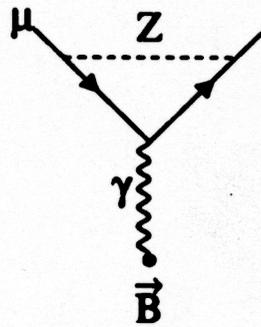
Standard Model Contributions

- electromagnetic (previous slide)

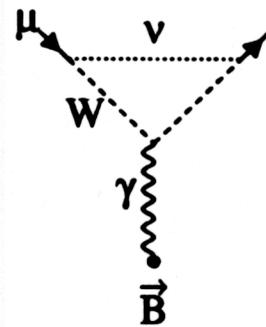
- hadronic, i.e.



- weak, i.e.

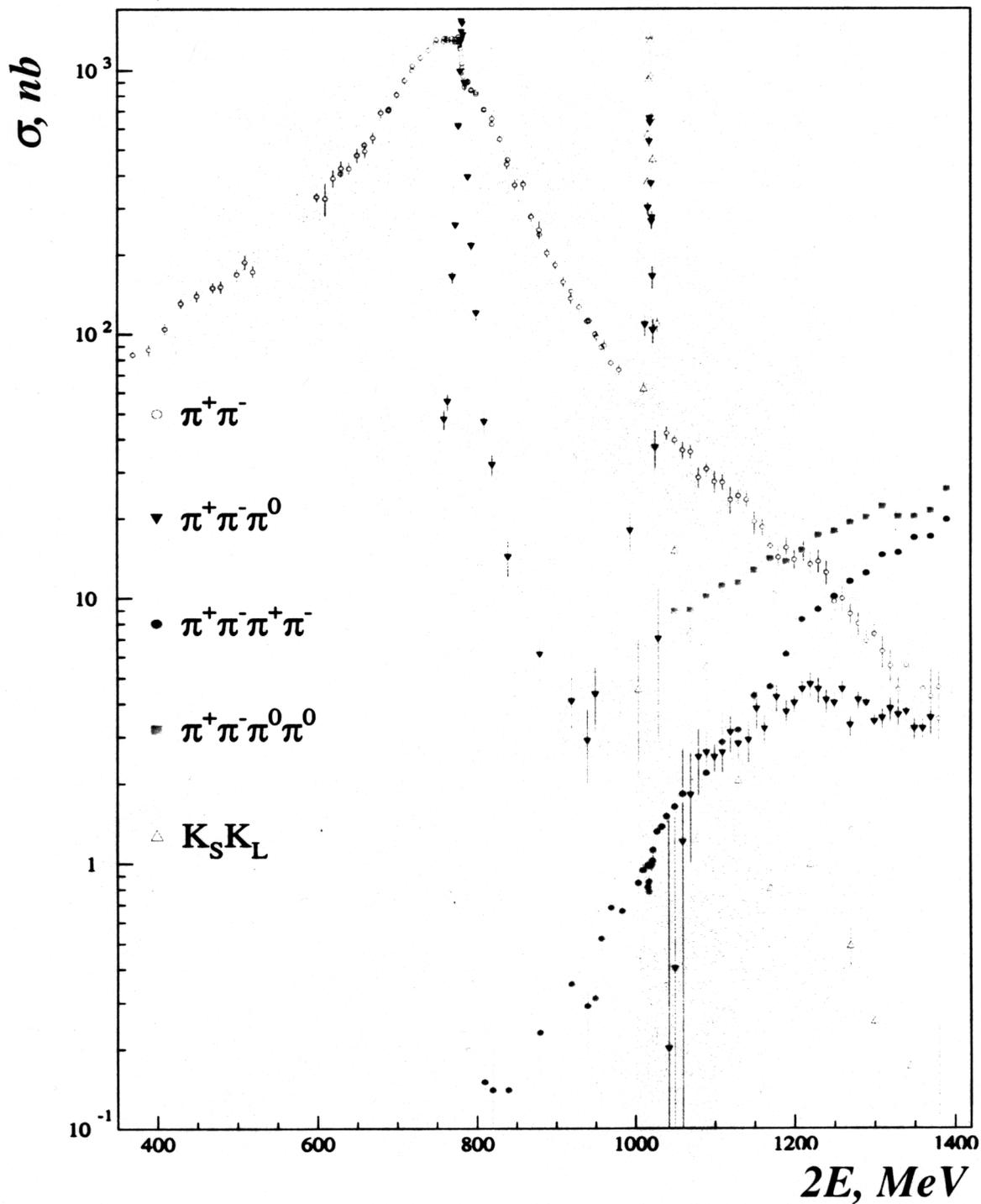


or



$$a^{\text{SM}} = a^{\text{em}} + a^{\text{had}} + a^{\text{weak}}$$

Measurements of $e^+e^- \rightarrow \text{hadrons}$ with CMD-2



Muon a_μ

enhancement for contributions involving massive particles compared to a_e :

$$(m_\mu/m_e)^2 \simeq 4 \times 10^4$$

| a_μ^{SM} | rel. contr. |
|-----------------------|----------------------------------|
| a_μ^{em} | $\approx 1 \pm (17 \text{ ppb})$ |
| a_μ^{had} | $(57.8 \pm 0.6) \text{ ppm}$ |
| a_μ^{weak} | $(1.3 \pm 0.03) \text{ ppm}$ |

$$a_\mu^{\text{SM}} = 116\,591\,601(64) \cdot 10^{-11} \quad (\text{using } \alpha \text{ from } a_e)$$

Hughes, Kinoshita, Rev. Mod. Phys., Vol. 71, No.2 (1999)
+ ref. therein + Davier, Höcker, Phys. Lett 435(1998) 427

CERN measurements: 7.2 ppm accuracy

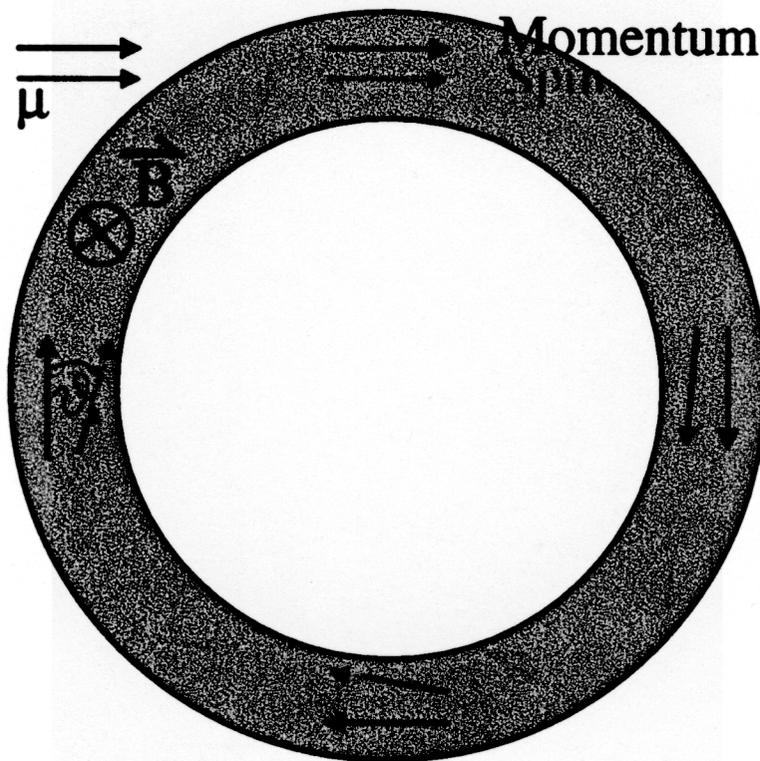
J. Bailey et al., Nucl. Phys. B150(1979) 1

Ultimate E821 Goal: 0.35 ppm accuracy

A.Steinmetz DNP99/6

Method

Store polarized muons in a homogenous magnetic field and measure difference frequency between spin and momentum precession



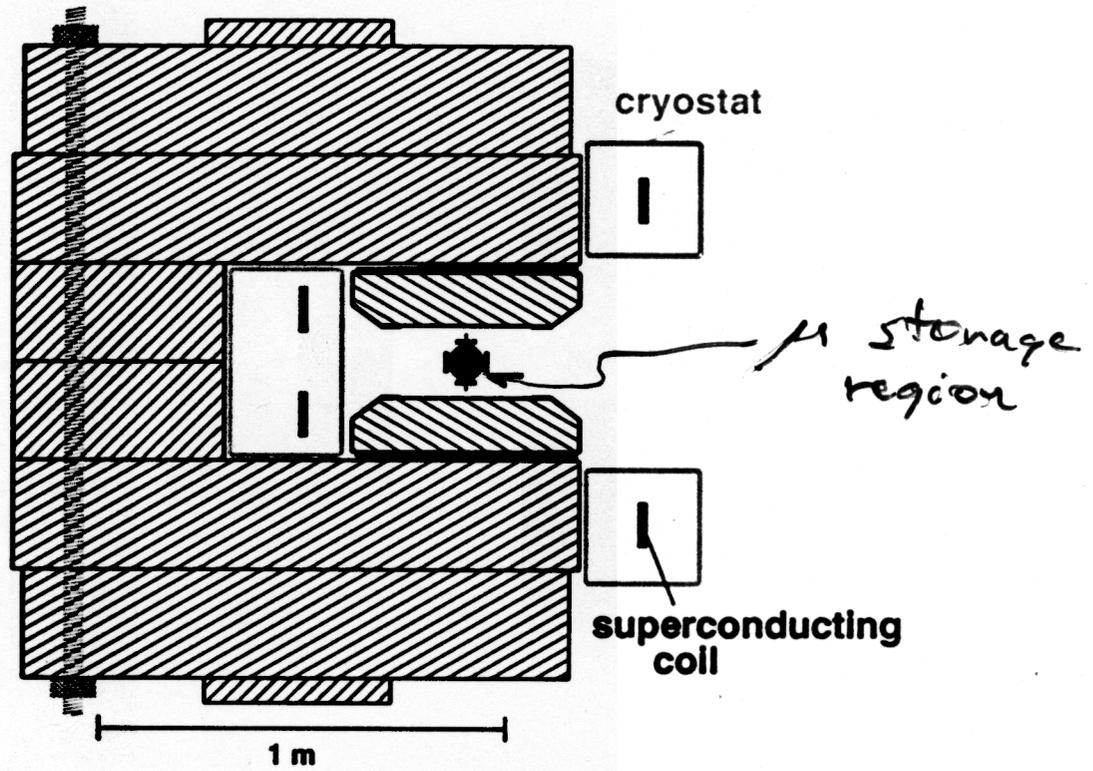
measure

$$\vec{\omega}_a = \frac{d\vec{\vartheta}_a}{dt} = \frac{e}{m_\mu c} a_\mu \vec{B}$$

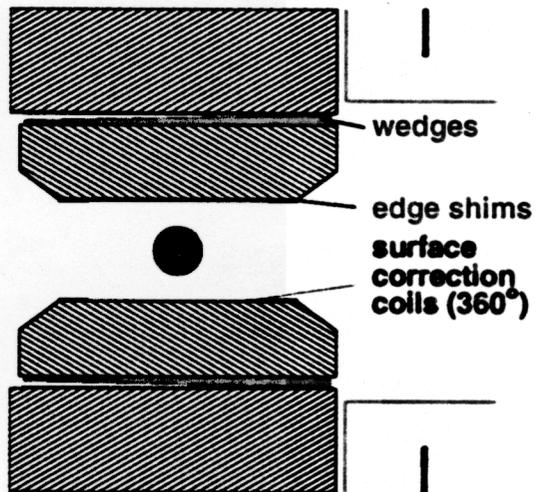
$\frac{g_\mu - 2}{2}$

A.Steinmetz DNP99/9

The E821 Ring Magnet



shimming tools:





8-2

photo RIPP BOWMAN

$$d \approx .002'' = 50 \mu\text{m}$$

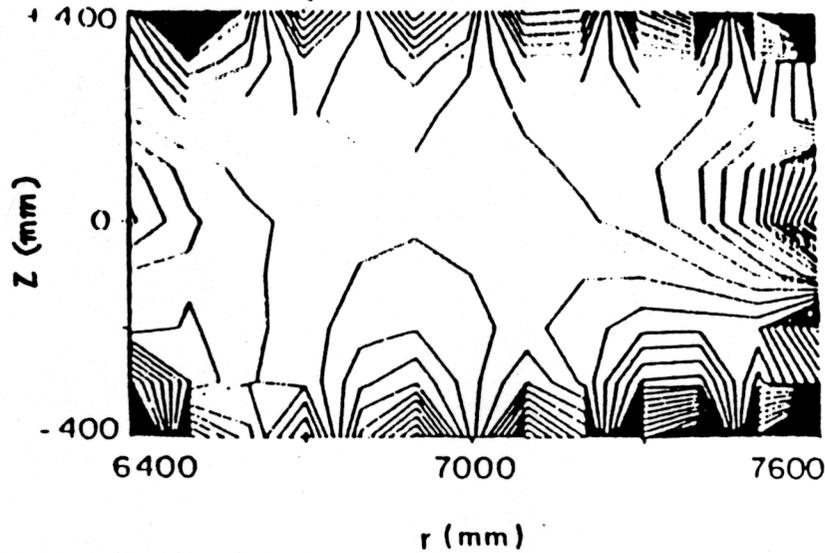
$$g-2 \text{ magnet gap} = 18 \text{ cm}$$

$$\therefore \frac{d(\text{hair})}{\text{gap}} = \frac{50 \times 10^{-6}}{2 \times 10^{-1}} = \boxed{250 \text{ ppm}}$$

The $g-2$ field uniformity, averaged over the azimuth (as the μs do) is now $\pm 1 \text{ ppm}$.

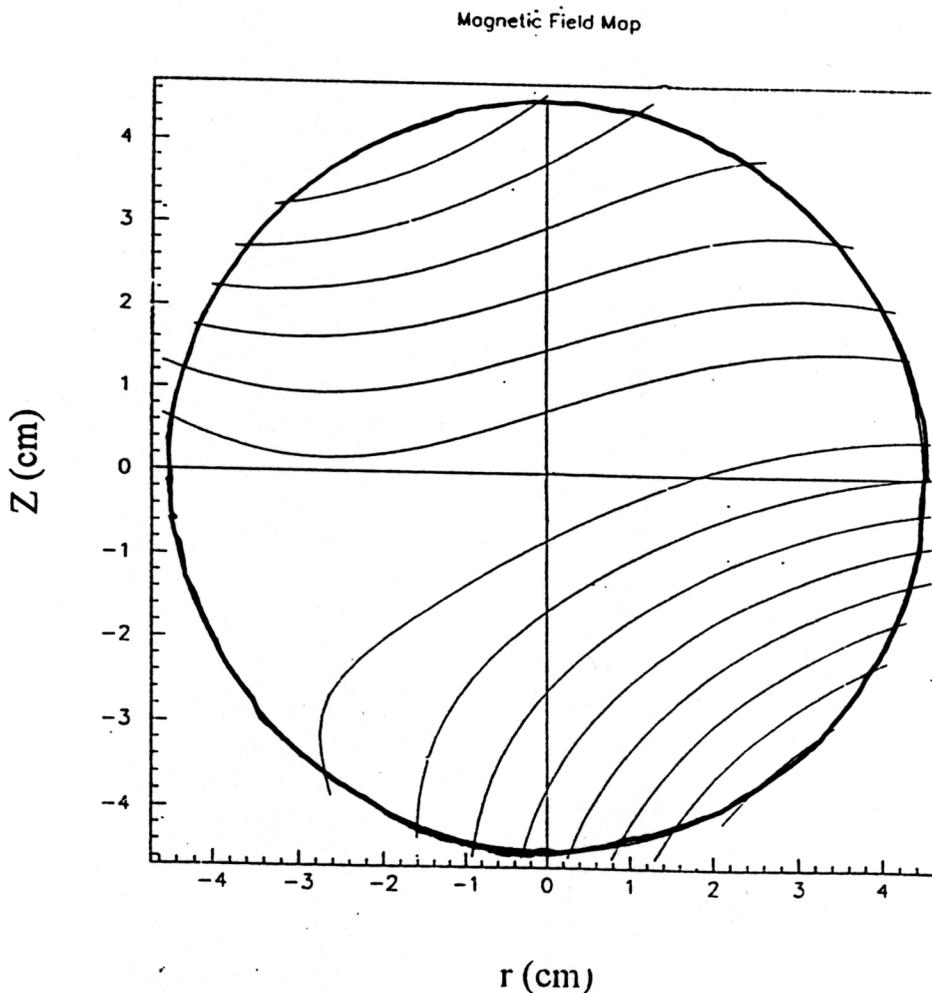
B-field Uniformity (2 ppm field lines)

J. Bailey et al. / CERN muon storage ring



CERN

Fig. 5. A contour line plot of the magnetic field strength in the muon storage aperture. This map is obtained by averaging a three-dimensional map in azimuth. The interval between the contours of equal field strength is 2 ppm or $3 \mu\text{T}$.

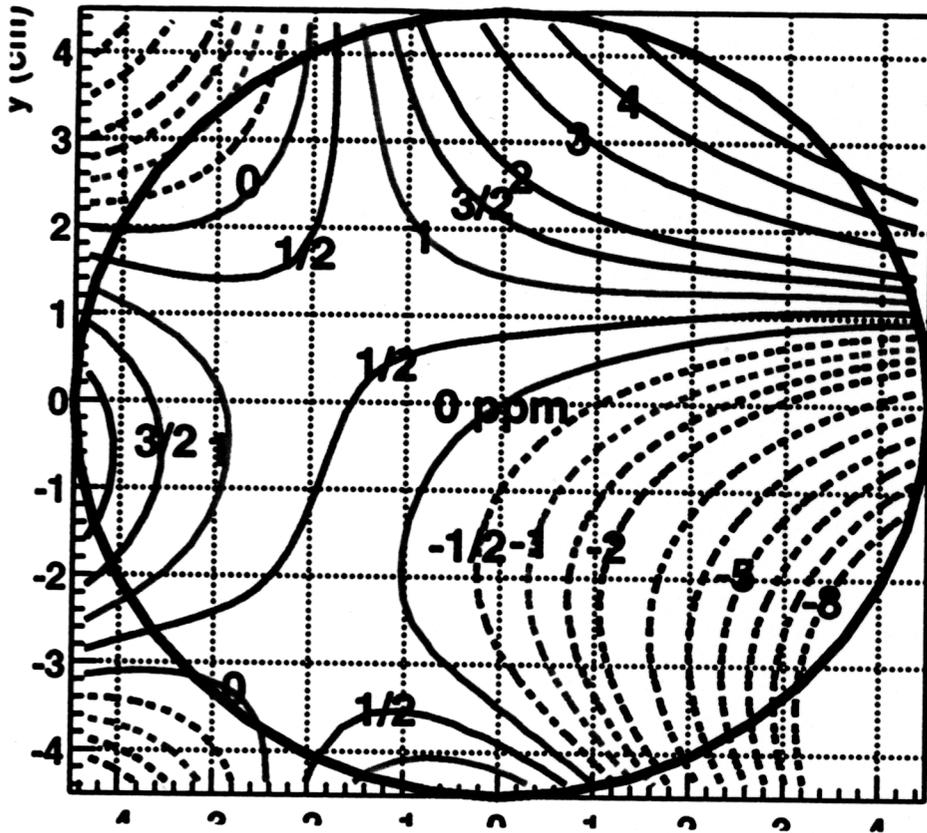


BNL 1st Run

E821 July, 1997

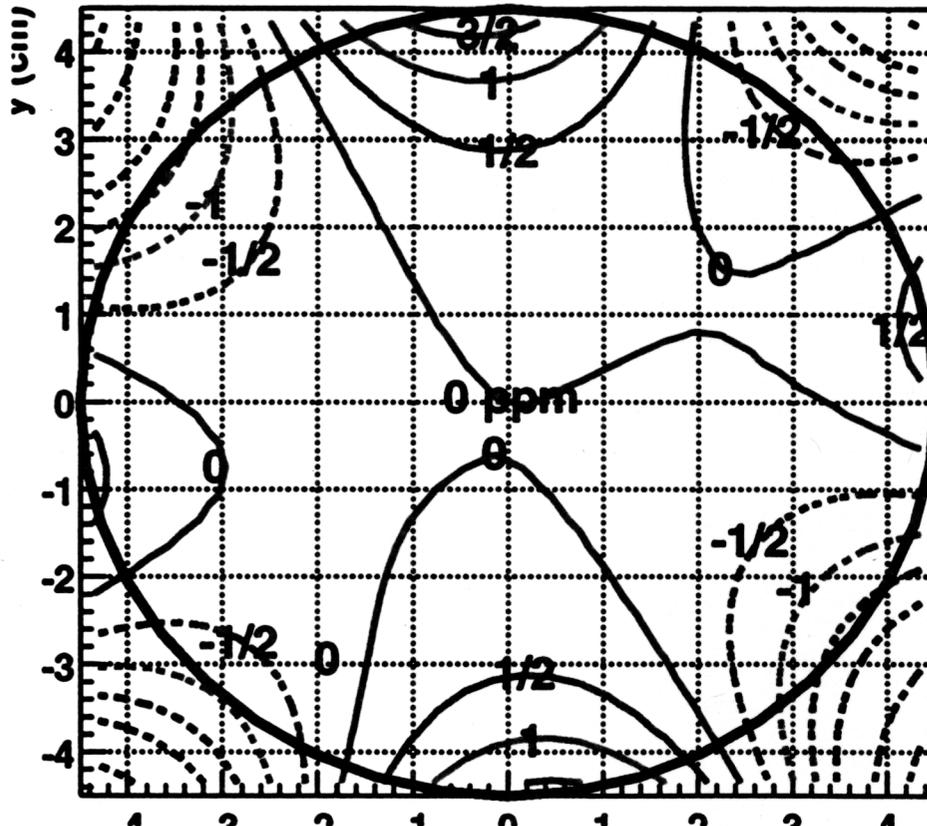
2 ppm
contour
lines

Multipole expansion of B field in 1999

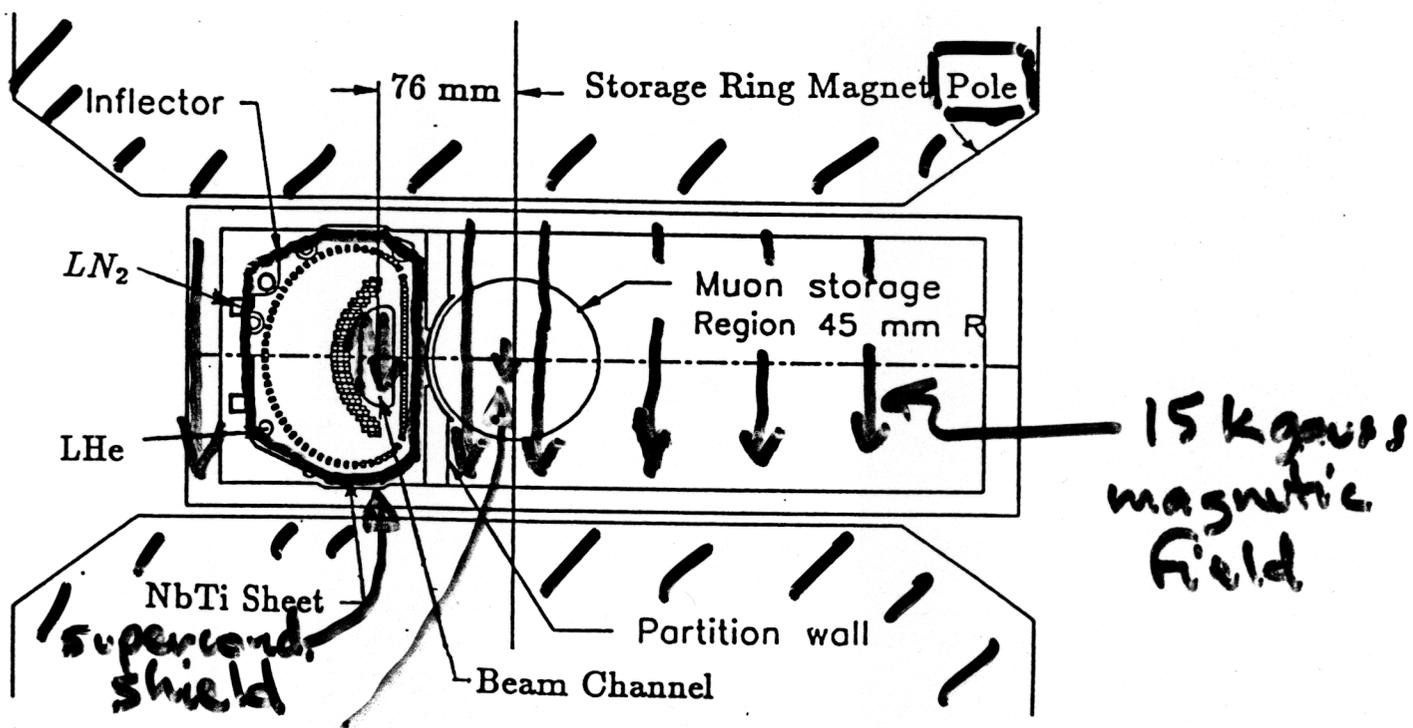
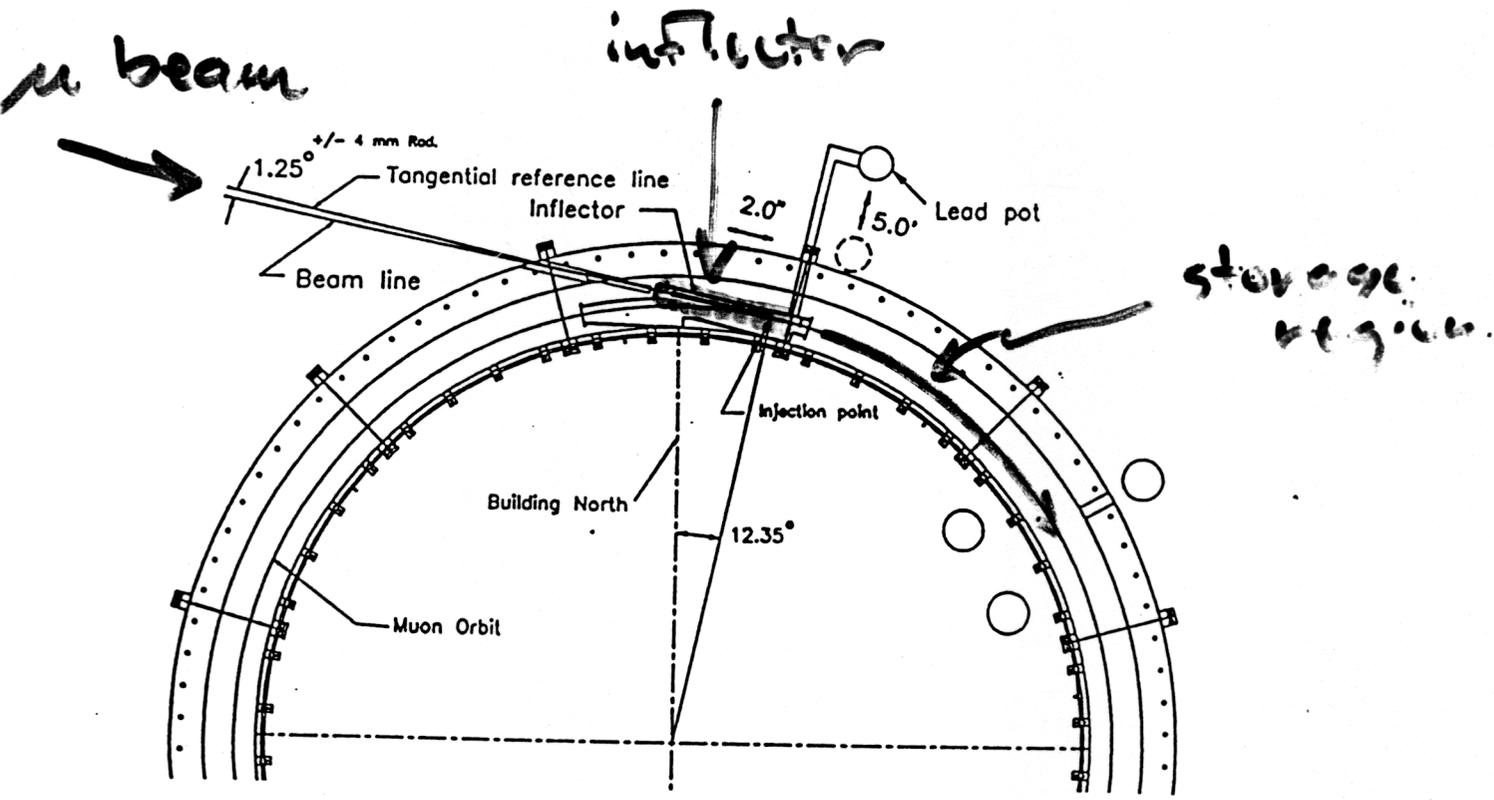


| Multipoles (ppm) | | |
|------------------|--------|------|
| | normal | skew |
| Quad | -1.80 | 2.73 |
| Sext | -1.61 | 3.70 |
| Octu | -1.29 | 1.76 |
| Decu | 0.91 | 0.72 |

Multipole expansion of B field in 2000



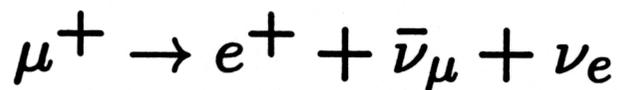
| Multipoles (ppm) | | |
|------------------|--------|------|
| | normal | skew |
| Quad | 0.03 | 0.09 |
| Sext | -0.63 | 0.27 |
| Octu | -0.02 | 0.00 |
| Decu | 1.09 | 0.53 |



20 gauss leakage from inflector field (without shield)

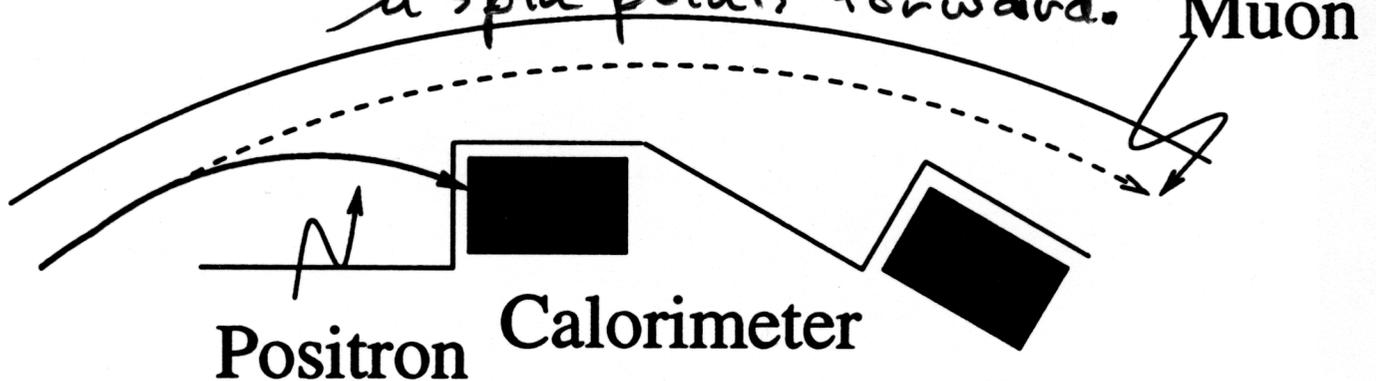
Polarimeter

high energy positrons from muon
decay

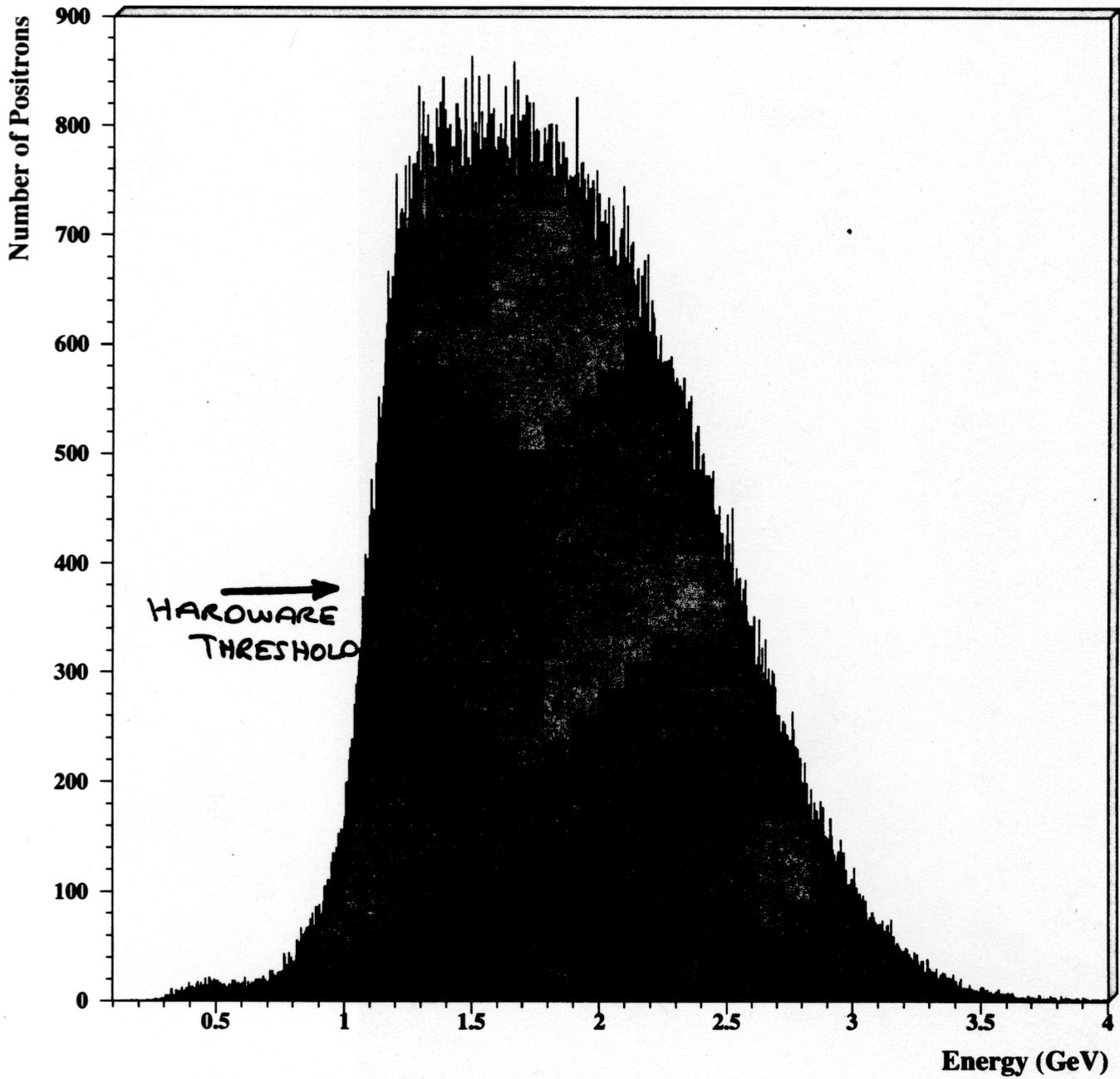


Parity violation: more e^+ in direction
of muon spin.

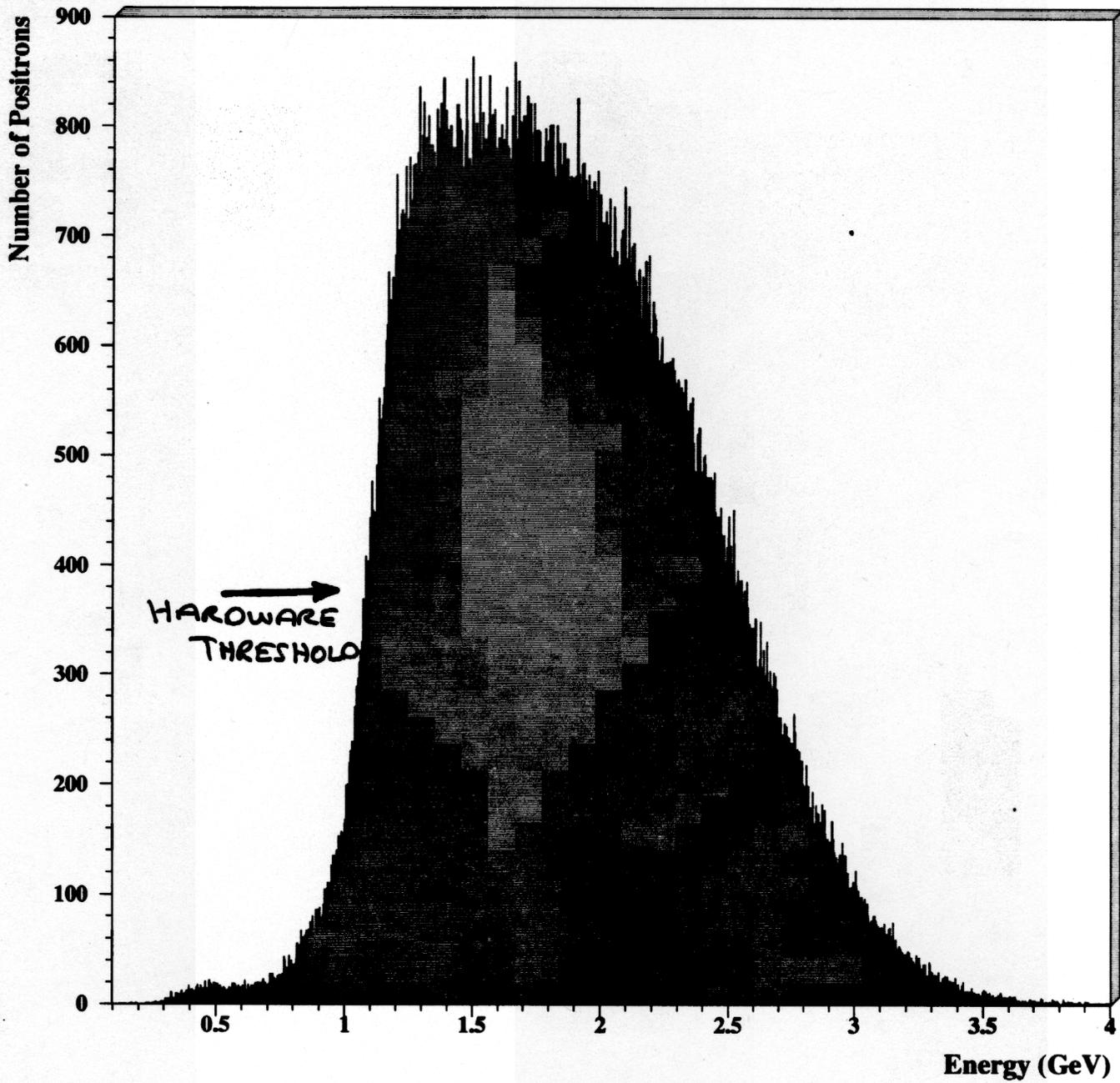
Boost: more high energy e^+ when
mu spin points forward.



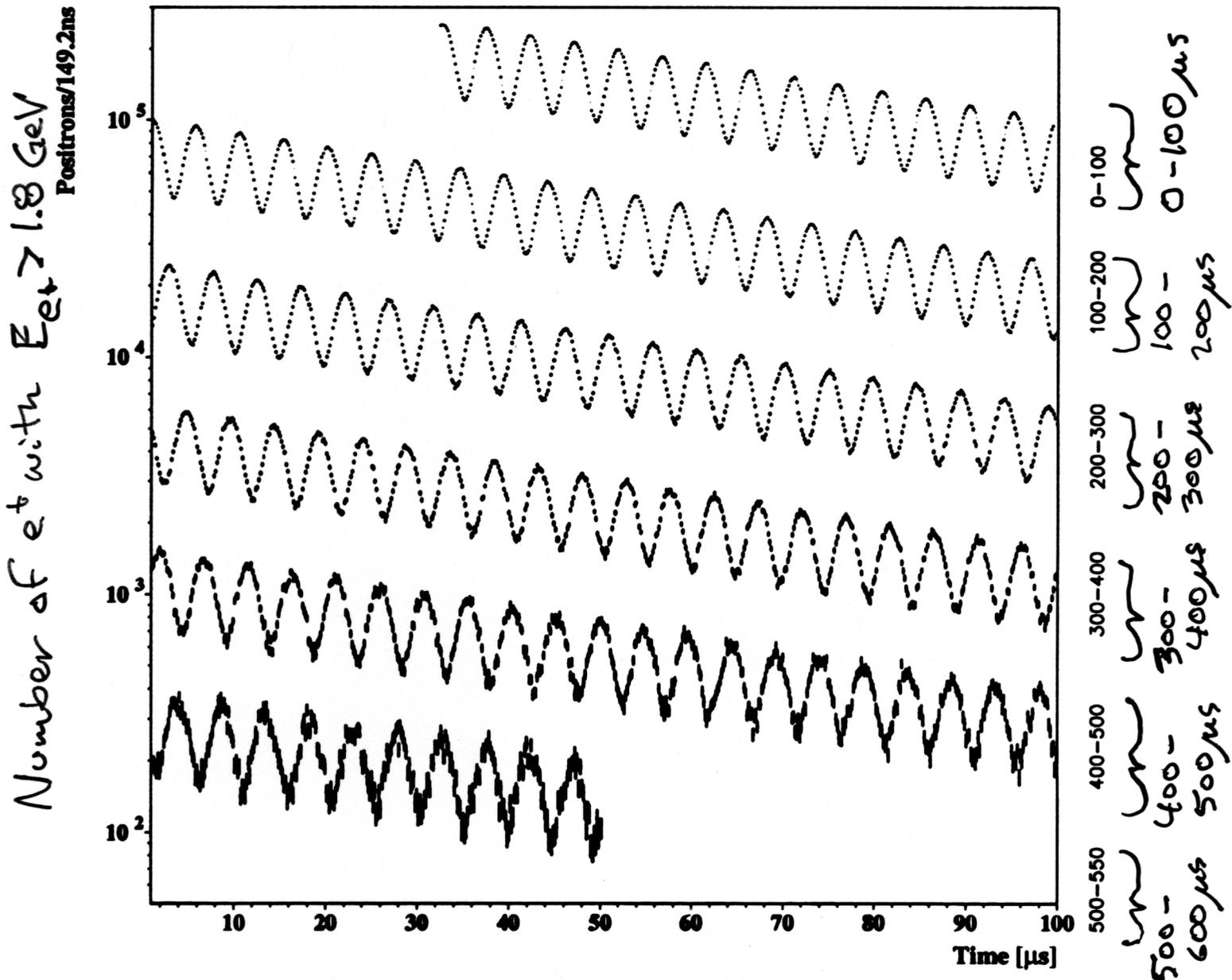
Decay e^+ spectrum at the PEAK of g-2 oscillation

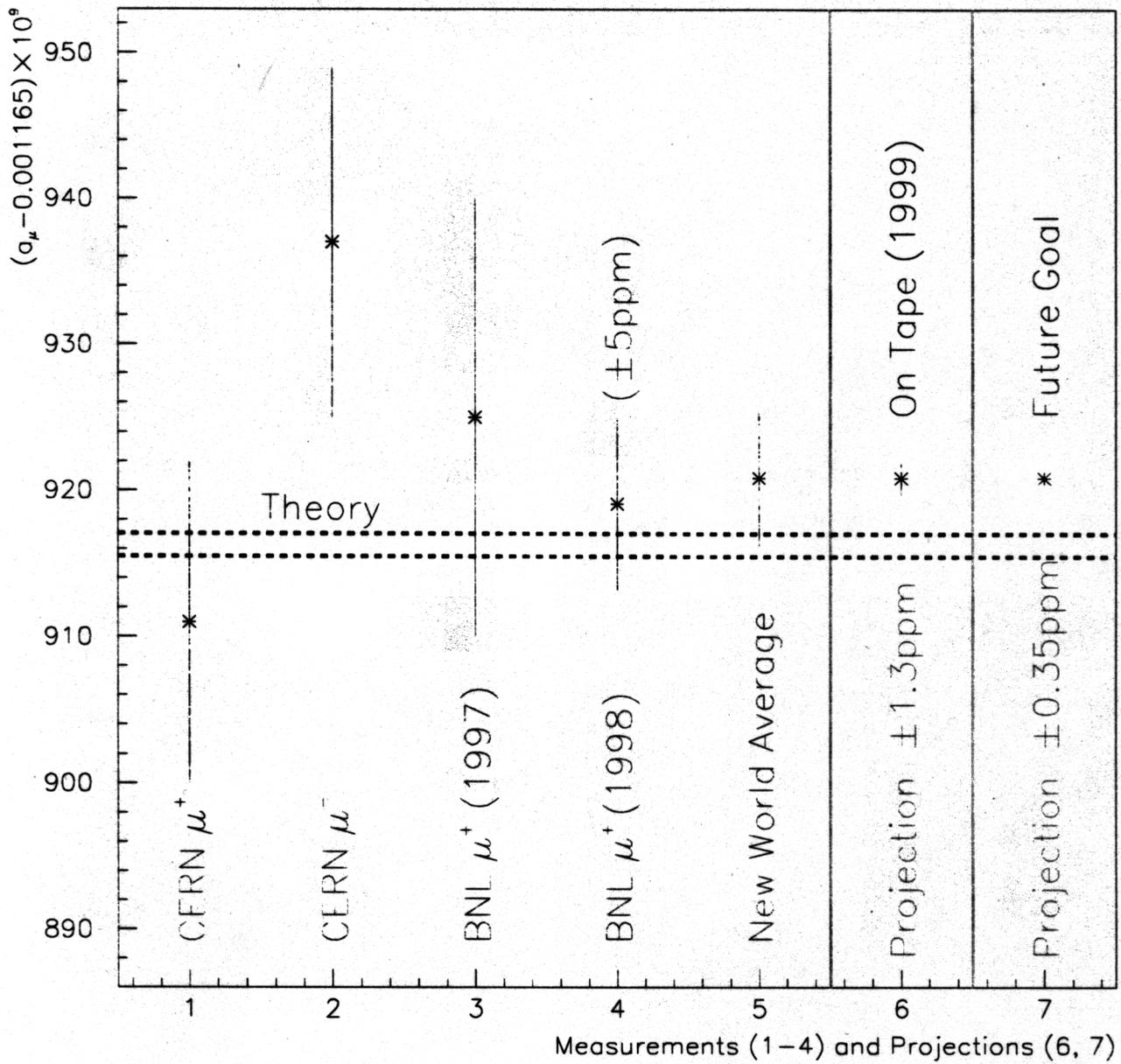


Decay e^+ spectrum at the PEAK of g-2 oscillation

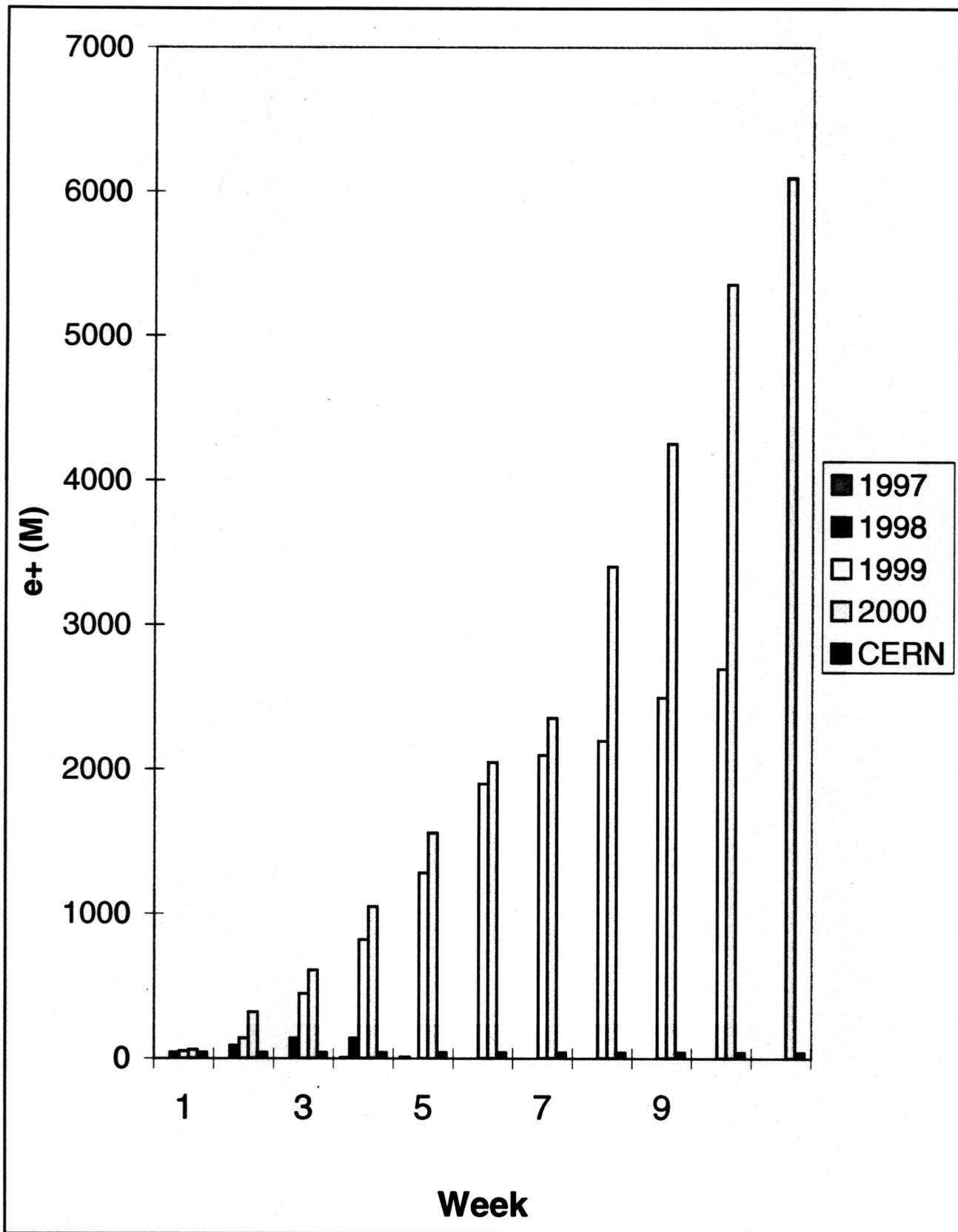


1998 Data
 (Cu lifetime at 3.1 GeV \approx 64 μ s)





Cumulative e+ (M) Chart 3



1999 ω_p Analysis

1. Data are energies every 2.5 nsec over a 1 GeV threshold.

2. Fit pulses, obtain pedestal, energy, time from injection.

—many details: pulse shapes, analyze pedestal vs. time, self-consistency checks; 2 approaches used, ...

3. g-2 “wobble” plot. Fit with 5 parameters:

$$F(t) = \underline{N_0} e^{-t/\underline{\tau}} \left[1 + \underline{A} \cos(2\pi \underline{f} t + \underline{\phi}) \right]$$

4. poor χ^2 : plot residuals

—coherent betatron oscillation from kick

—also seen in fiber monitor

—include CBO in fit

5. fast rotation—beam arrives bunched, 149 nsec period of ring

—bin in 149 nsec bins

—also generates pile-up

—used to study pile-up

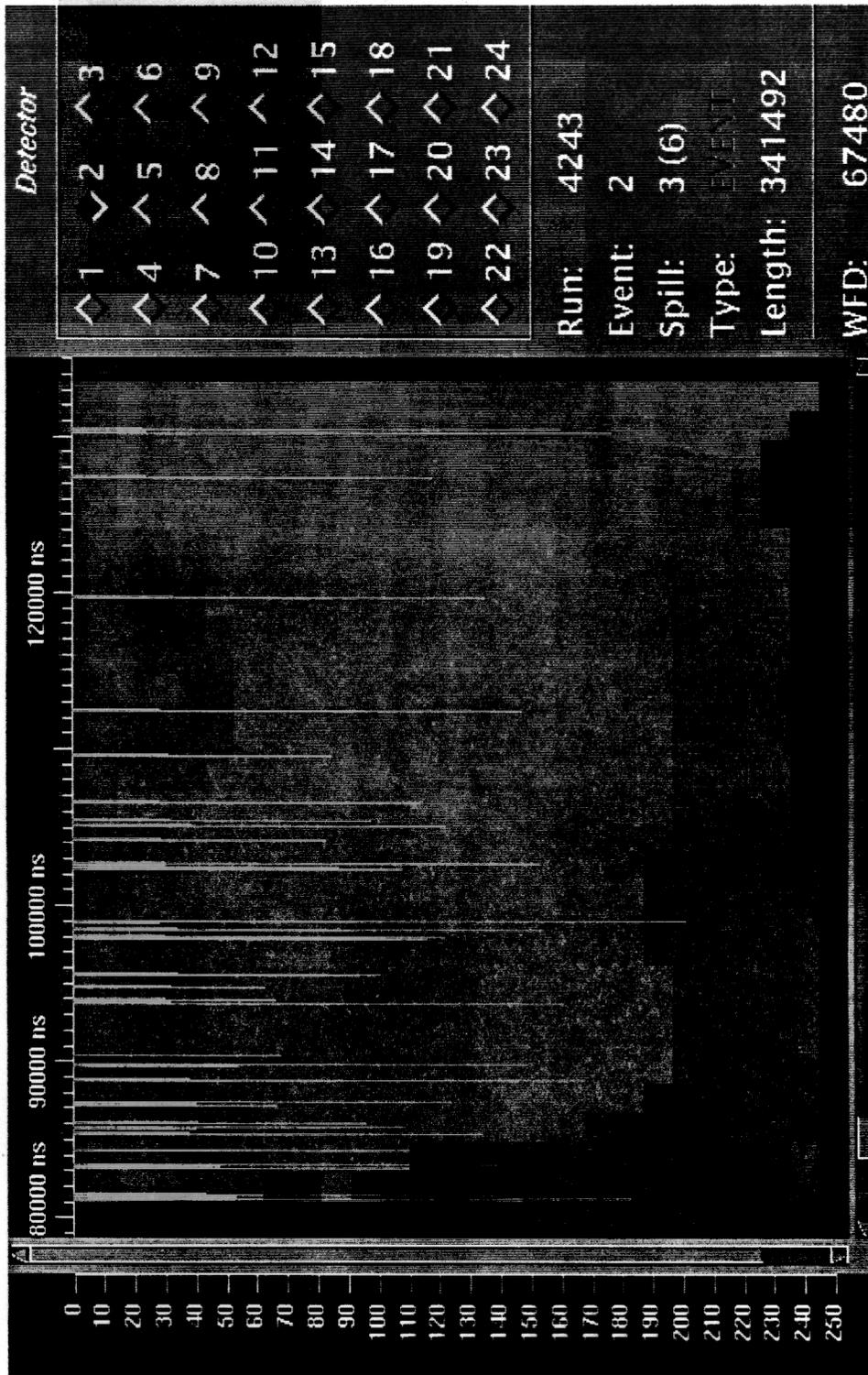
6. pile-up—more at early times than late

—use “shadow” pulses to directly measure and remove pile-up

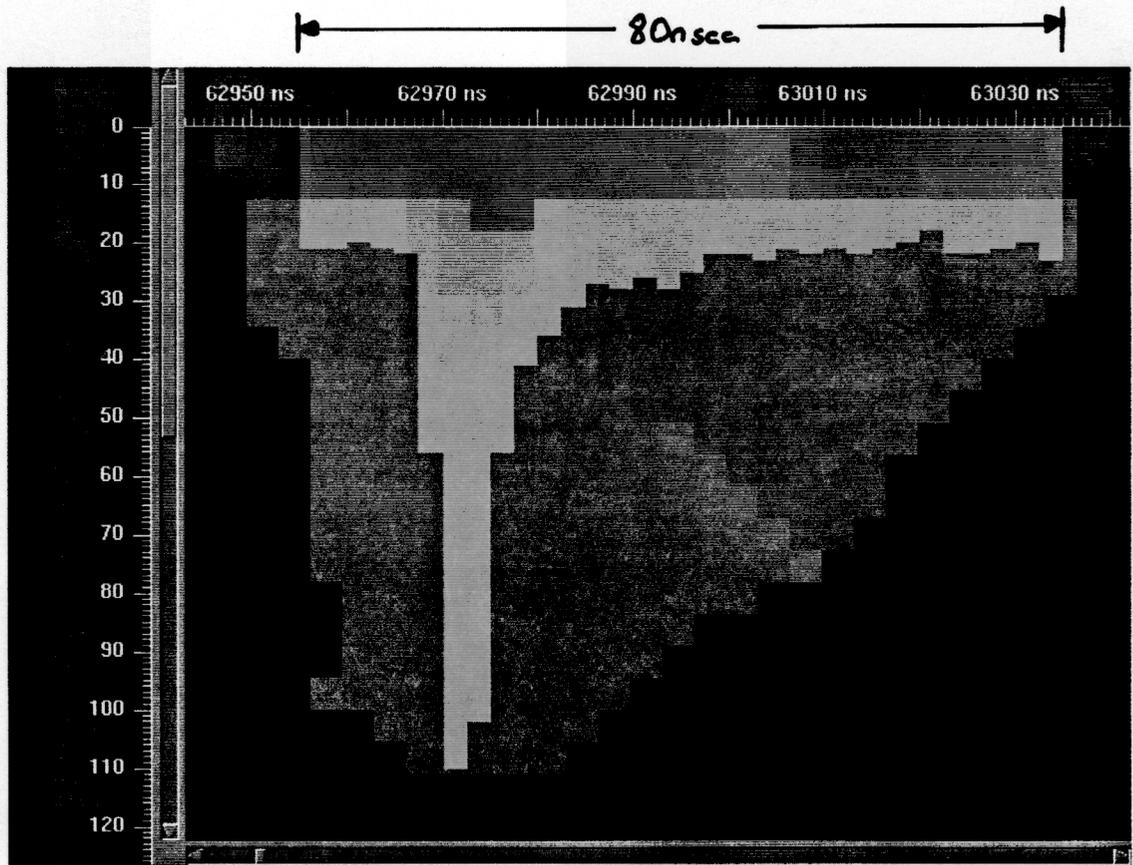
7. average energy seen in detectors vs. time—flat!

8. χ^2/DF flat, 0.995, all fit parameters well behaved vs. start time.

Muon Injection

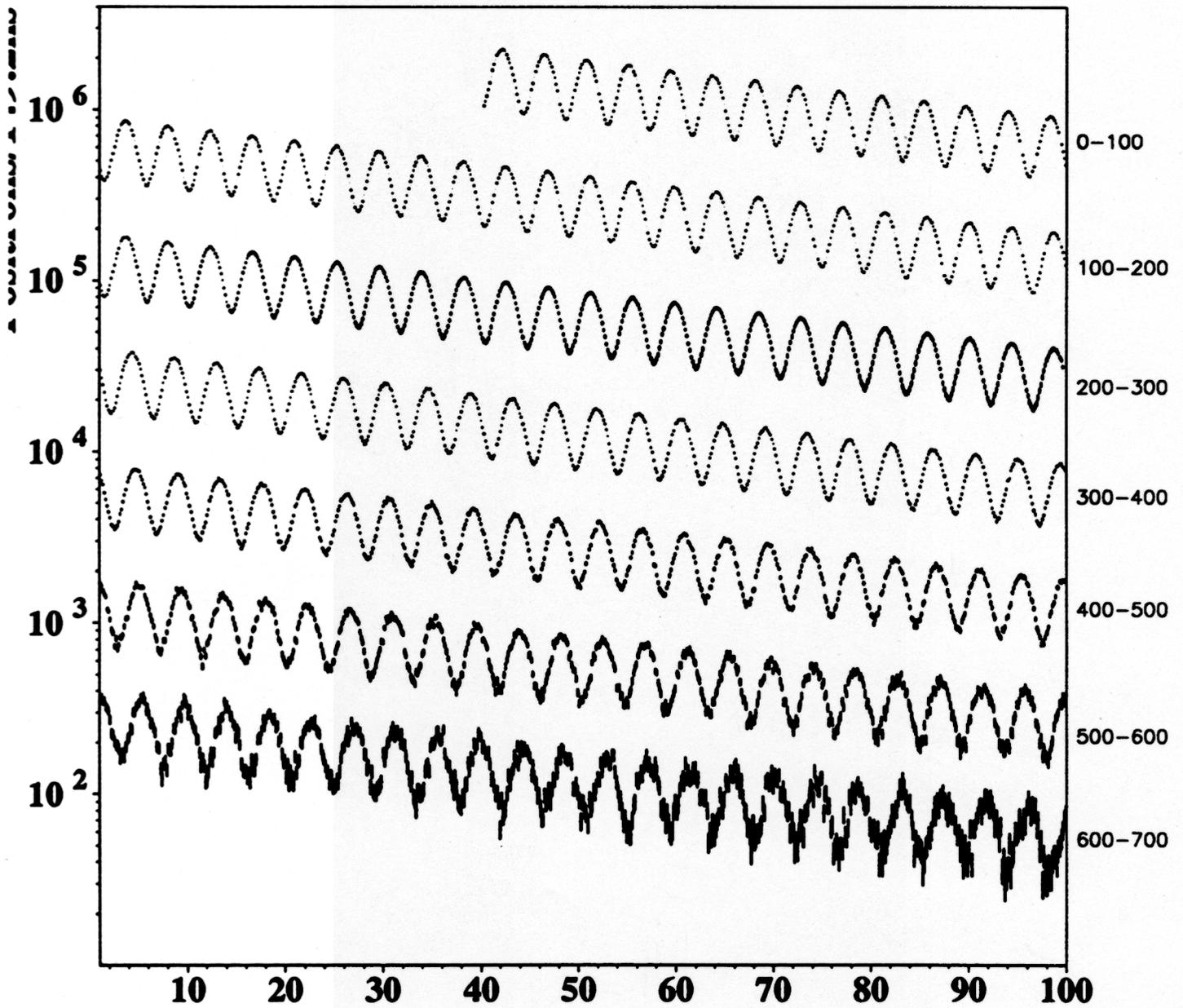


Positron Signal

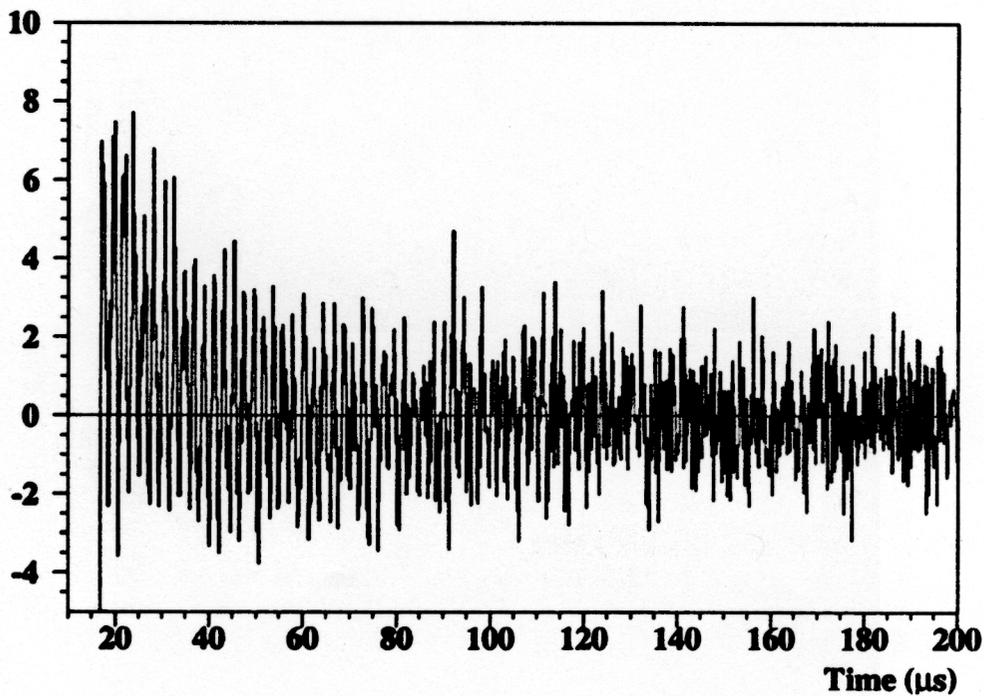


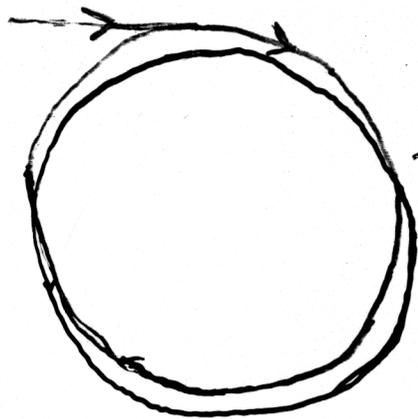
digitized with 400 MHz

1999 Data

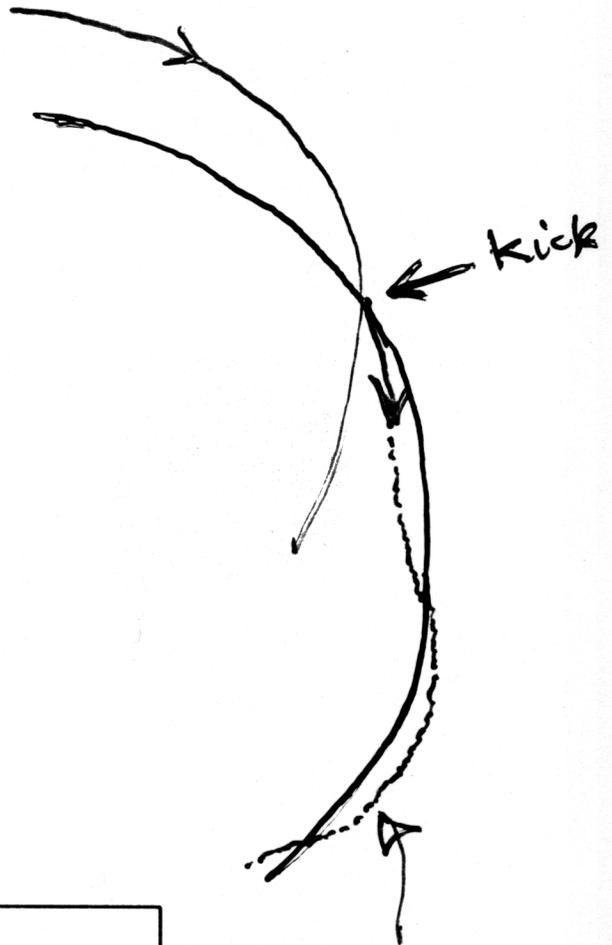


Residuals from 5 parameter
fit to "wiggle" plot:

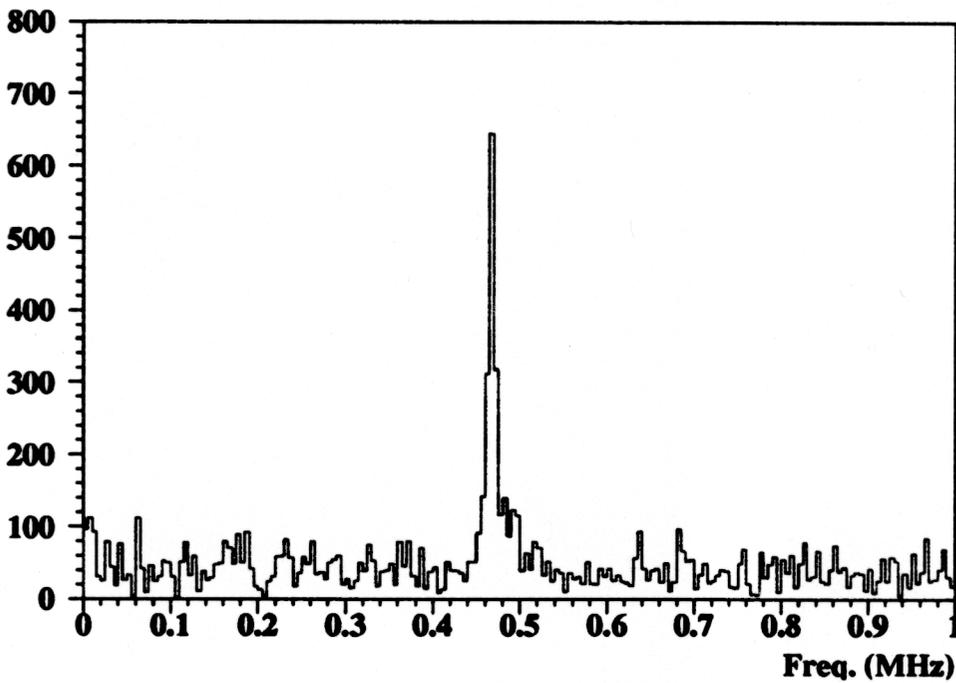




← kicker



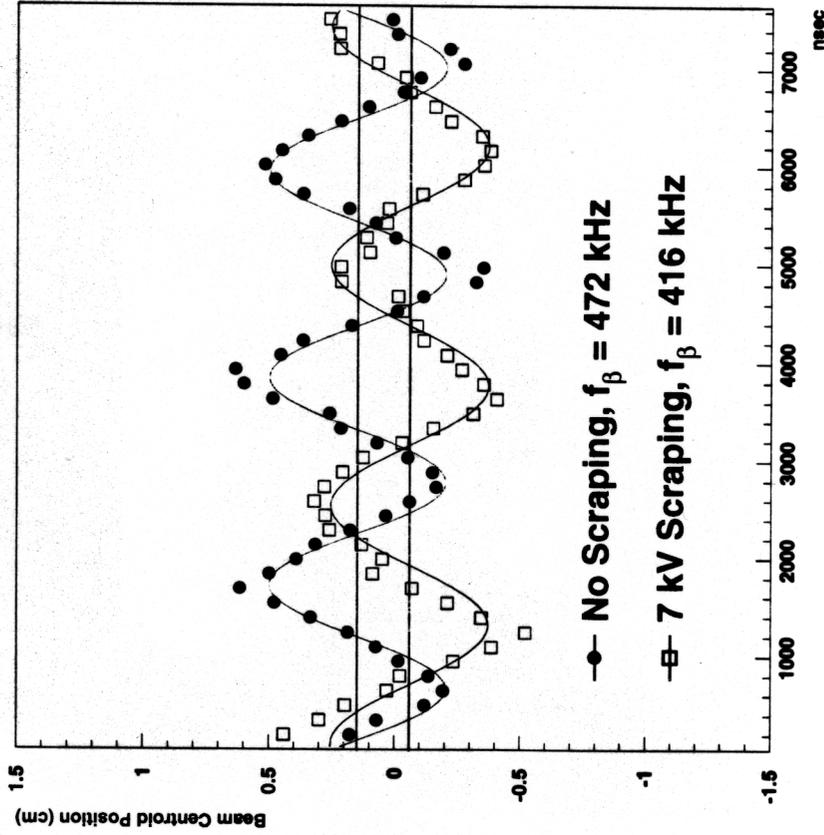
Frequency analysis of residuals:



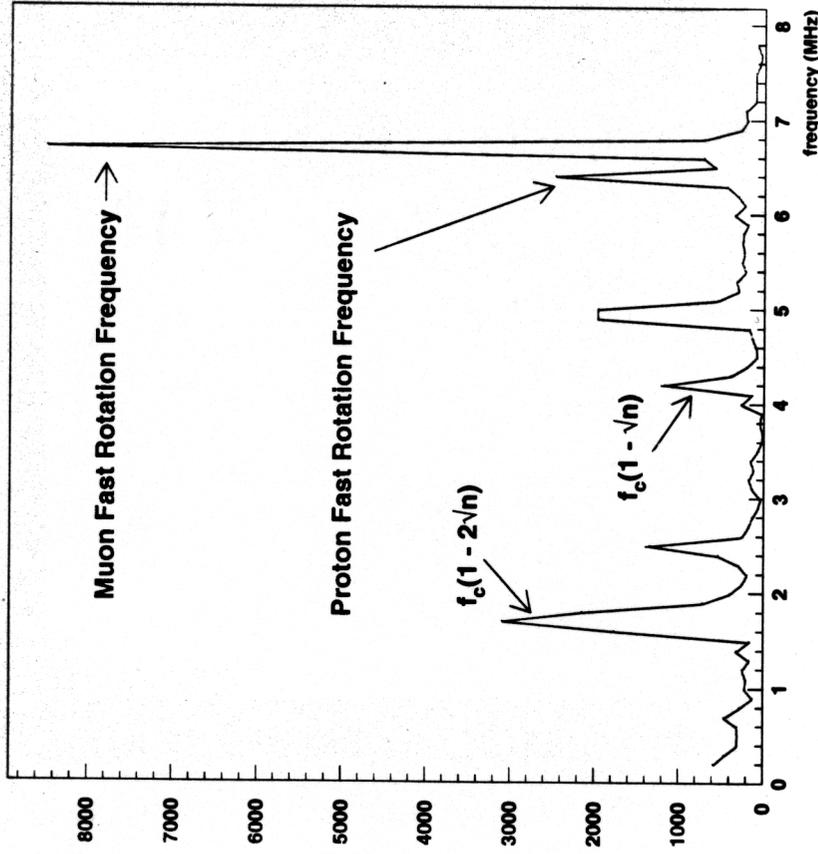
Coherent
Betatron
Oscillation
(exaggerated)
from insufficient
kick

Measurement of Beam Dynamics and Composition

Turn-by-turn Evolution of Radial Beam Centroid



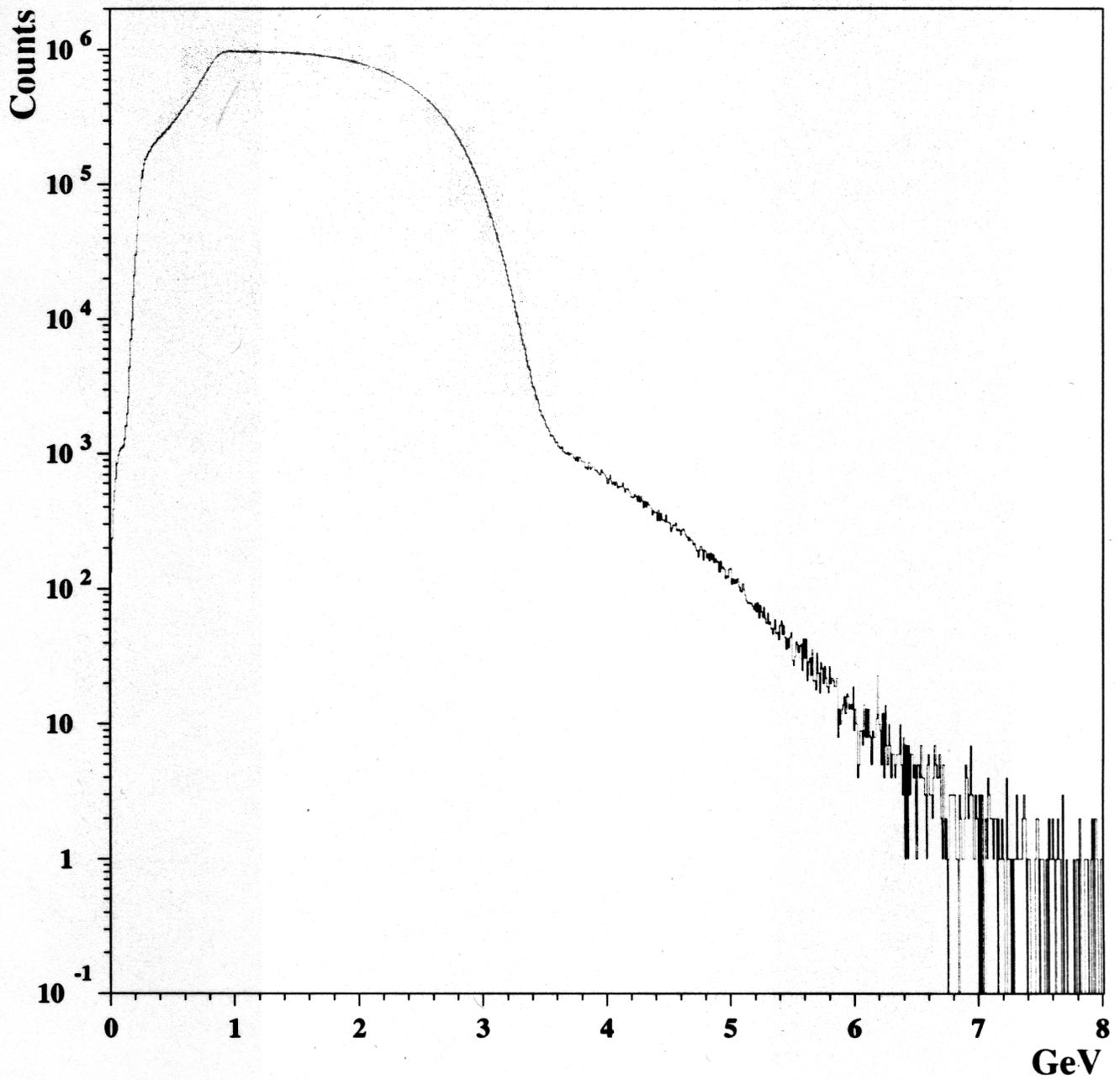
Fast Fourier Transform of Single Fiber Trace



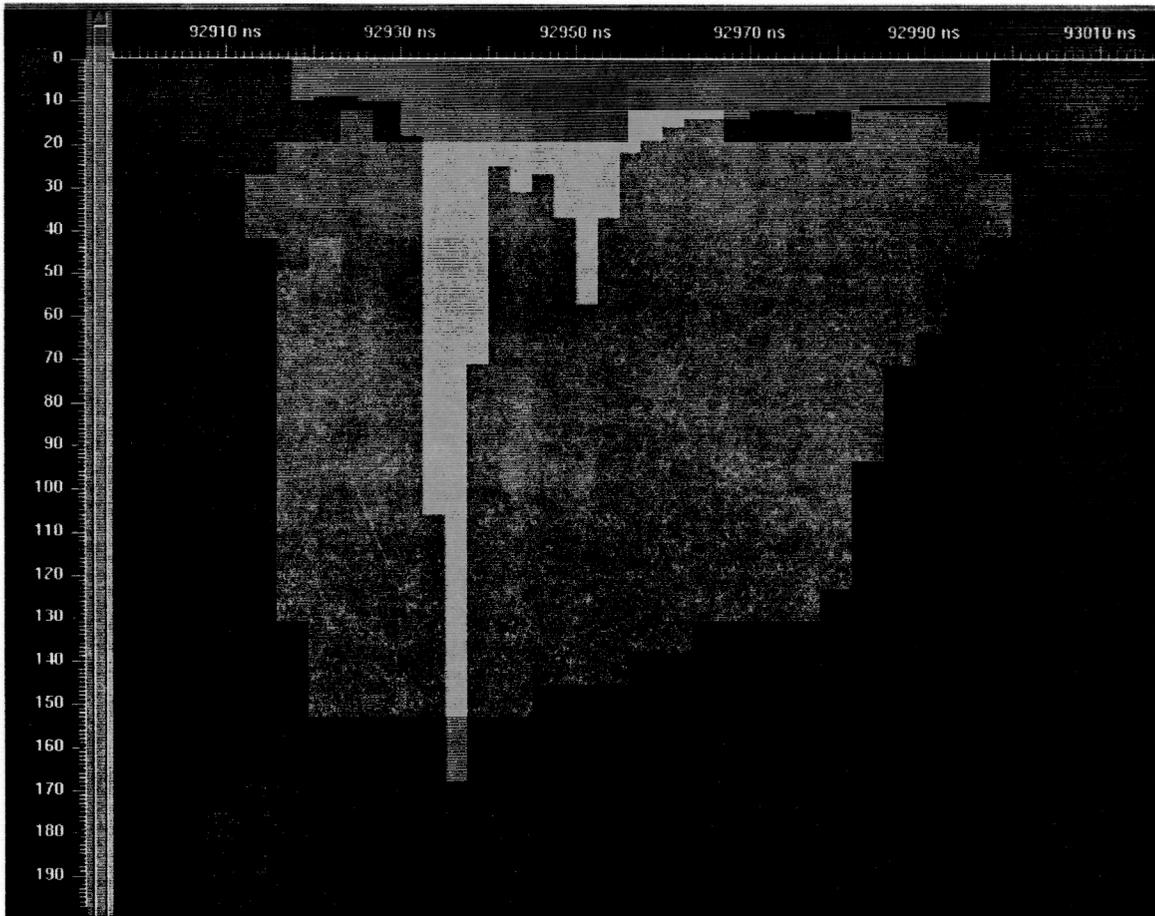
n-value of storage ring changes from 0.136 to 0.120 during 7 kV quadrupole scraping

Measurement of fast rotation frequency, betatron frequency, and evidence of stored protons

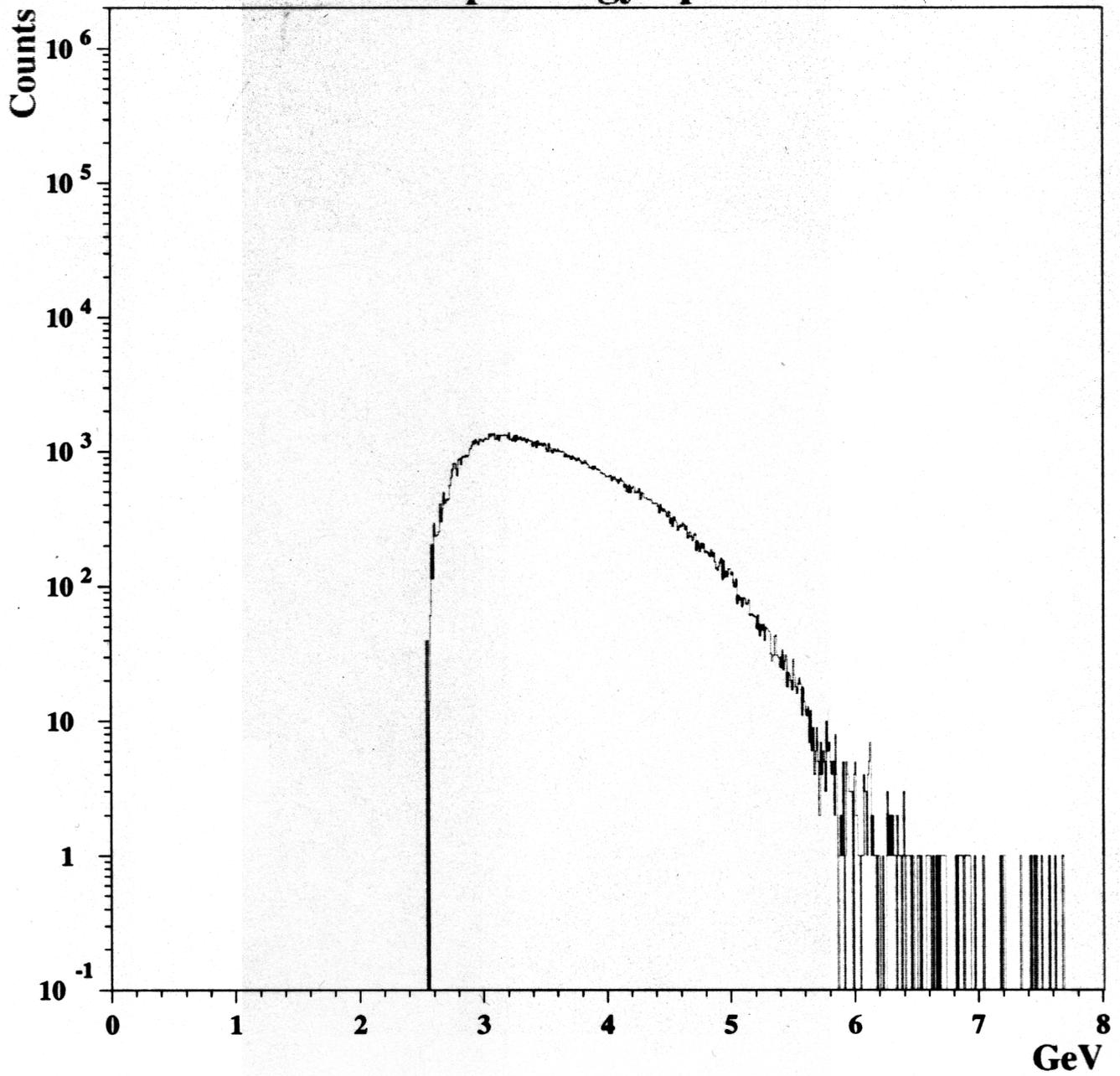
Detected Positron Energy Spectrum



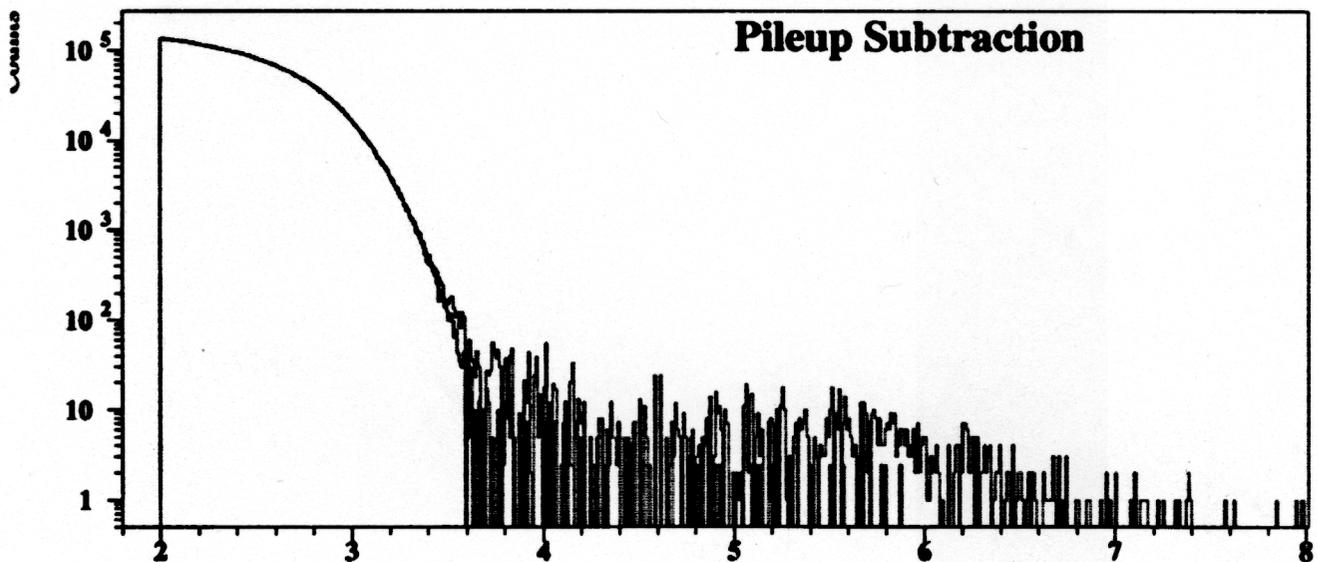
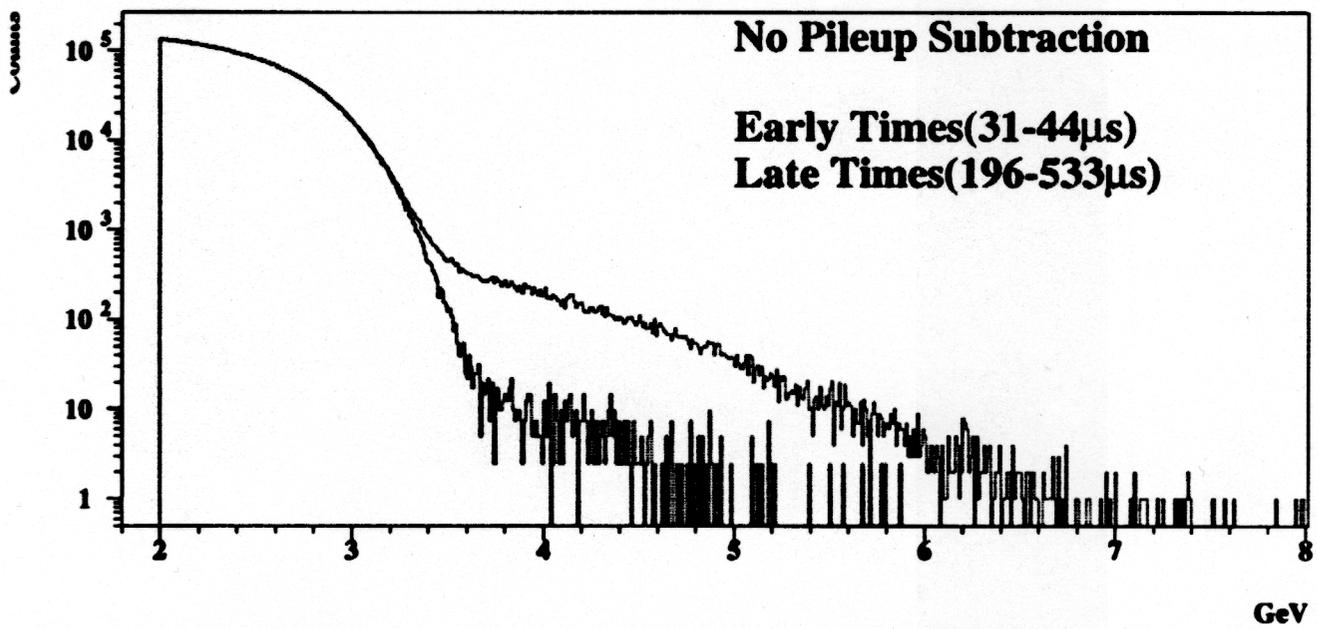
Double Pulse



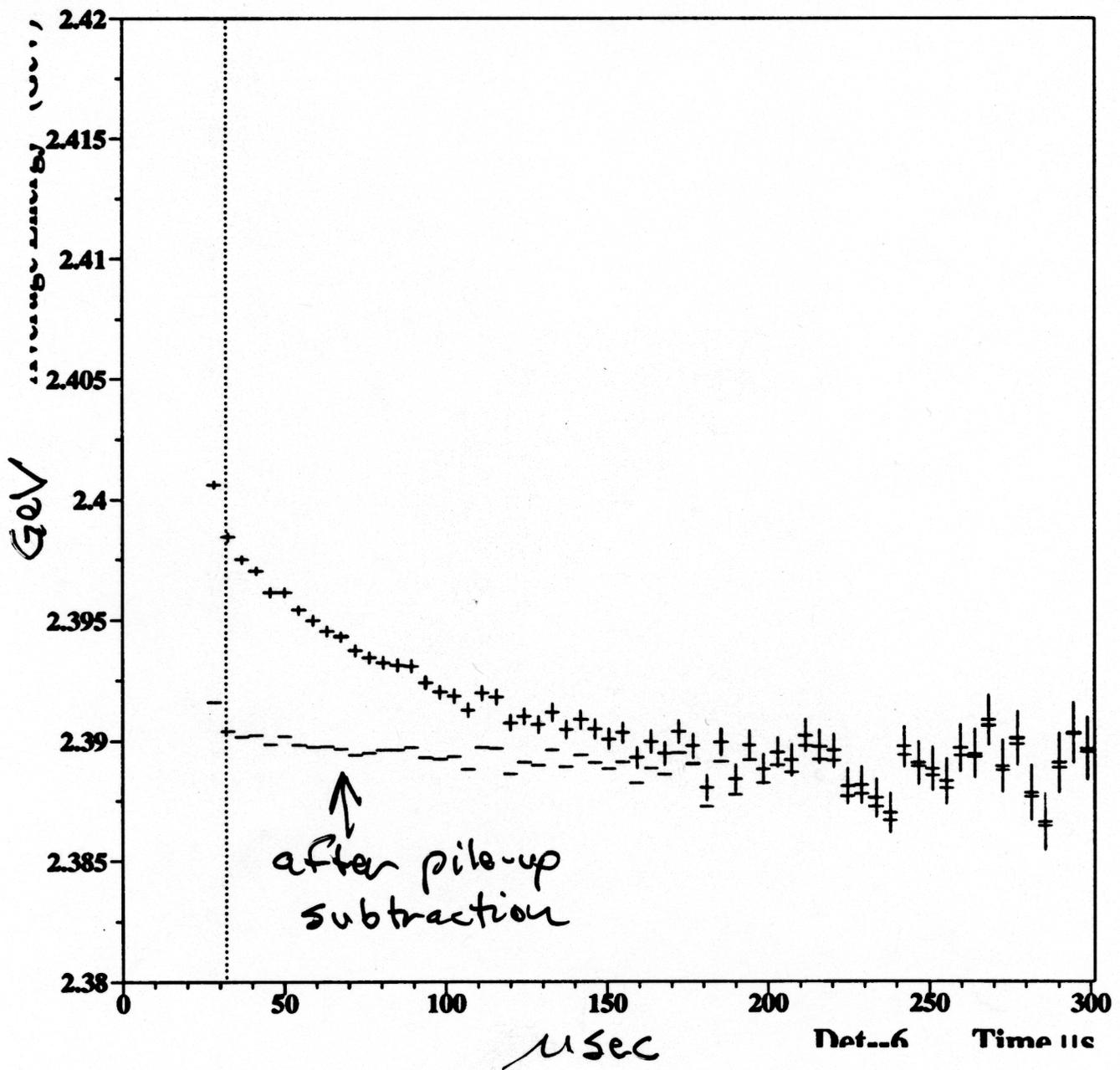
Pileup Energy Spectrum



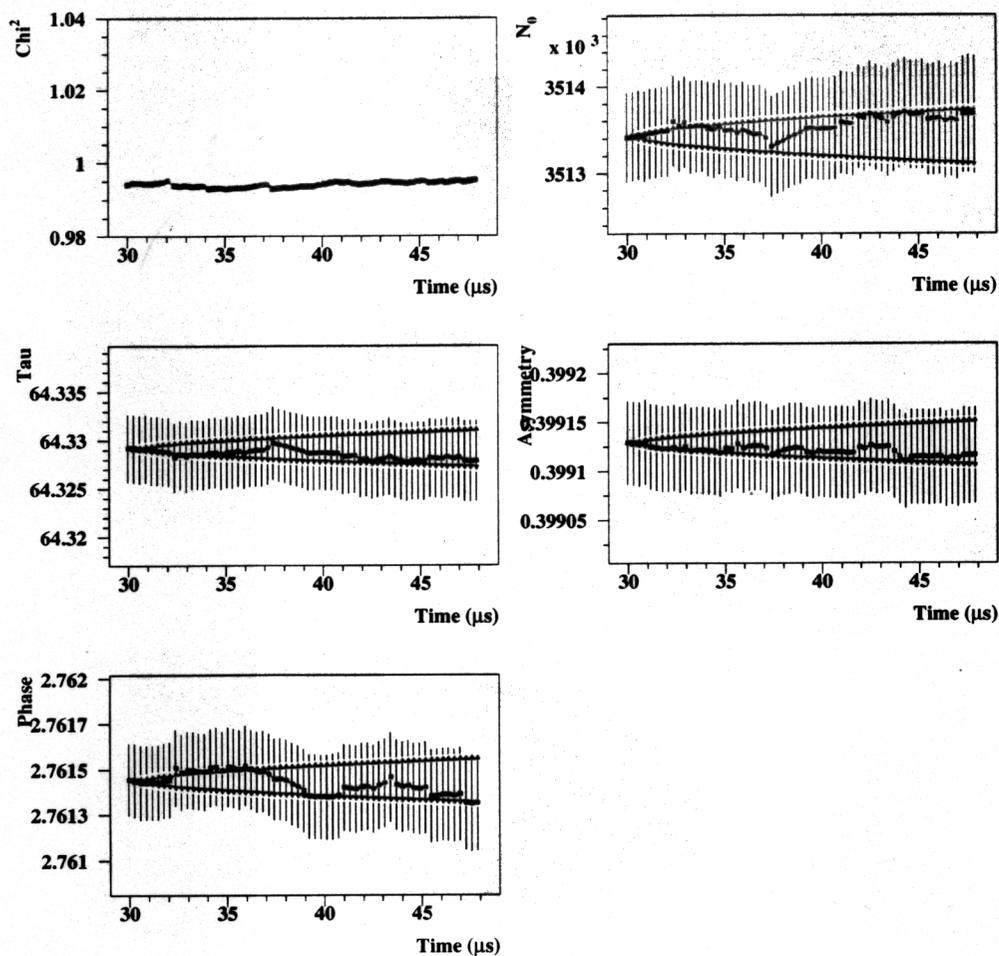
Energy Spectra



Average Energy seen in Detector 6 vs. time after injection

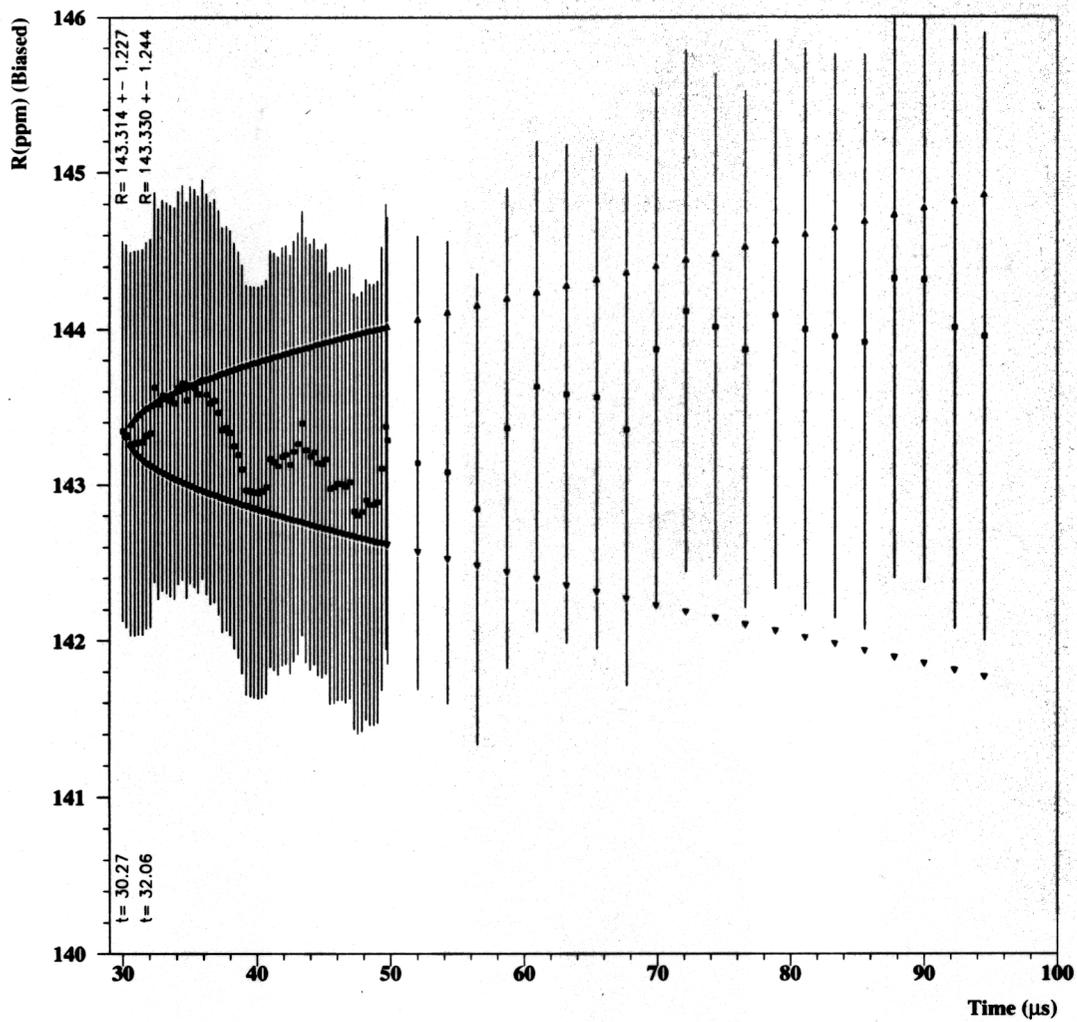


Pileup Subtracted



Fits to the data after pileup subtraction.

Pileup Subtracted



Fits to the data after only pileup subtraction.

Future

1. Complete 1999 analysis: expect +/- 1.3 ppm.
2. 2000 analysis going on now
 - field plot!
 - expect +/- 0.5 ppm
3. run in 2001 with μ^- : hope for +/- 0.5 ppm
4. Electric Dipole Moment for μ^- in 2001 run
 - CERN 3.7×10^{-19} e.cm
5. $\pi \rightarrow \mu + \nu$ in ring $\Rightarrow m(\nu_\mu)$ to 8 KeV
 - factor 10 improvement for direct measurement
6. letter of intent: EDM(μ) to 10^{-24} e.cm

E821 Collaboration (1999)

R.M. Carey, W. Earle, E. Efstathiadis, E.S. Hazen, F. Krienen,
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R. Prigl, Y.K. Semertzidis, D. Warburton - **Brookhaven Na-
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† **Co-Spokesmen**

‡ **Resident Spokesman**

§ **Project Manager**

Beyond the Standard Model

large variety of possible contributions:
(sensitivity limits for $\sigma_{a_\mu} = 0.35$ ppm)

- muon substructure: $a^{\mu-substr.} \sim \left(\frac{m_\mu}{\Lambda}\right)^2$
sensitivity: $\Lambda \approx 5$ TeV, LHC domain
- W anomalous magnetic moment a_W
sensitivity: ~ 0.02
LEP II: ~ 0.05 , LHC: ~ 0.2
- W substructure: $a^{W-substr.} \sim \left(\frac{m_W}{\Lambda}\right)^2$
sensitivity: $\Lambda \approx 400$ GeV
LEP II: $\sim 100 - 200$ GeV
-

(T. Kinoshita and W. Marciano, in "Quantum Electrodynamics",
ed. T. Kinoshita (World Scientific, Singapore 1990))

Beyond SM (cont.)

- Supersymmetry (for large $\tan\beta$)

$$a_{\mu}^{SUSY} \approx 140 \cdot 10^{-11} \left(\frac{100 \text{ GeV}}{M_{SUSY}} \right)^2 \tan\beta$$

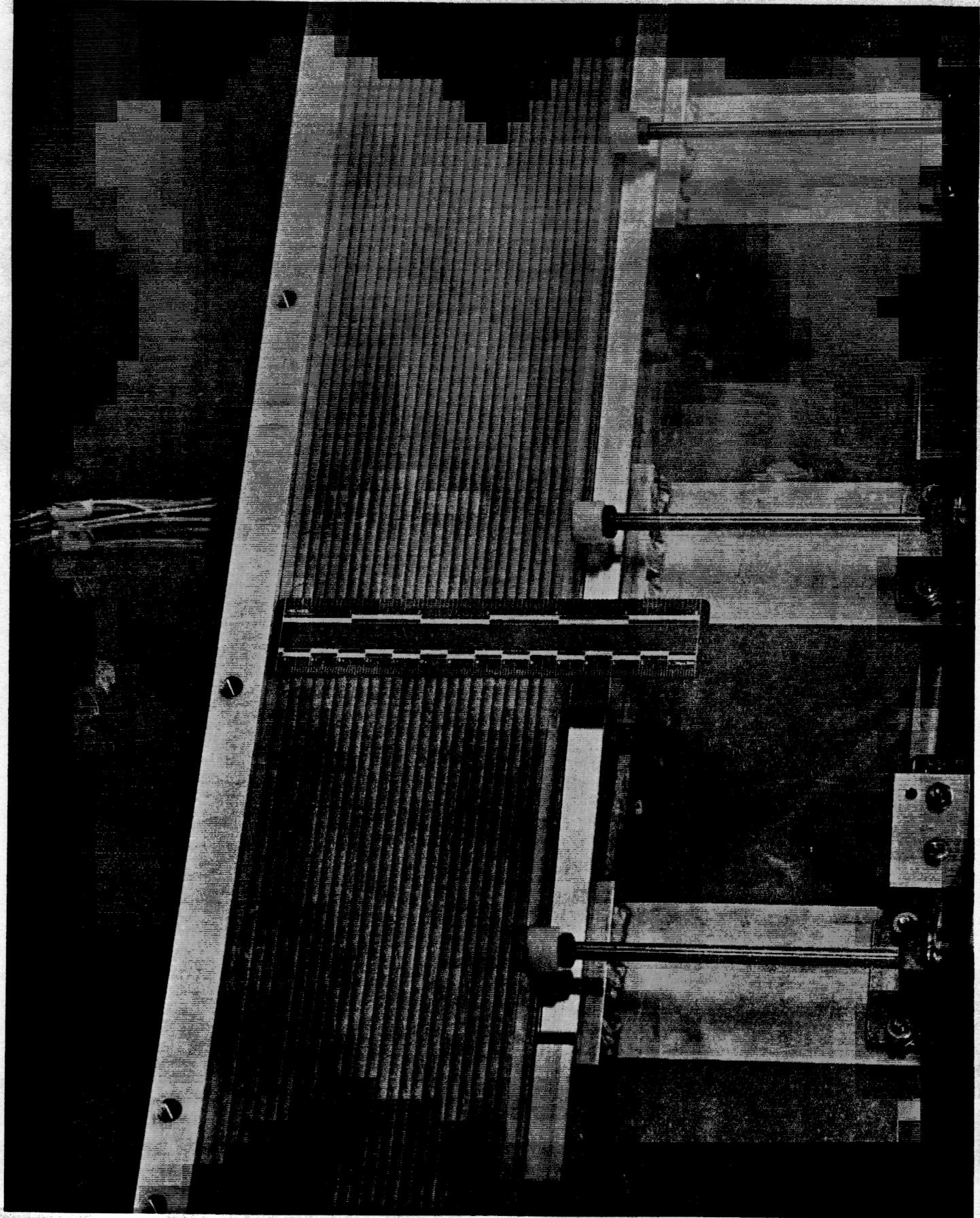
i.e. $\tan\beta = 40$,

$$\text{if } M_{SUSY} = 1.2 \text{ TeV} \rightarrow a_{\mu}^{SUSY} \approx 0.35 \text{ ppm}$$

$$\text{if } M_{SUSY} = 700 \text{ GeV} \rightarrow a_{\mu}^{SUSY} \approx 1 \text{ ppm}$$

$$\text{if } M_{SUSY} = 350 \text{ GeV} \rightarrow a_{\mu}^{SUSY} \approx 4 \text{ ppm}$$

1P-5561-Y 43



654 KODAK

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4-532-93

